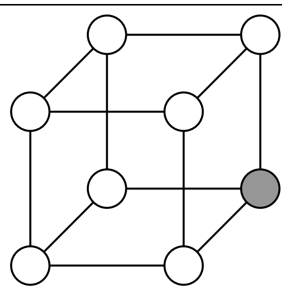
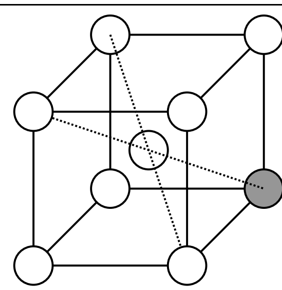
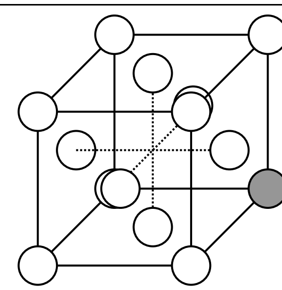
Post AP Exam Topics

Lesson-1

I – The Crystalline Structure of Metallic Solids

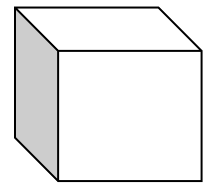
- Solids tend to crystallize in definite geometric forms because their particles are arranged in definite three-dimensional patterns.
- The particles may all be the same (metals) or different (salts).
- In a crystalline solid, the ***crystal lattice*** is an array of points that defines the positions of the particles in the crystal.
- In a crystalline solid, the ***unit cell*** is the simplest array of points that produces the lattice.
- Of the 14 different unit cell systems, the three simplest are:

Simple cubic	**Body-centered cubic**	**Face-centered cubic**
		
coordination # = 6	coordination # = 8	coordination # = 12
1 atom per unit cell (***52.36% filled***)	2 atoms per unit cell (***68.02% filled***)	4 atoms per unit cell (***74.04% filled***)
$s = \frac{4r}{\sqrt{4}} = \mathbf{2r}$	$s = \frac{4r}{\sqrt{3}}$	$s = \frac{4r}{\sqrt{2}}$

- The volume of a unit cell is equal to: $V_{cell} = s^3$
- The volume of a unit cell is always greater than the sum of the volumes of the atoms in the unit cell because the atoms do not completely fill a unit cell (***there is empty space in the unit cells***).

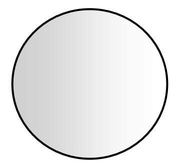
- In pure metallic solids, the ALL the particles are identical.
- Since all particles in pure metals are the same size, then the volumes of the unit cells are directly related to the radii of the unit particles.
- The general equation below relates the length of one edge (s) of the unit cell to the unit cell's coordination number (c#) and the radius (r) of the unit particles in the crystal.

$$s = \left(\sqrt{\frac{2c\#}{3}}\right)(r) \quad \rightarrow \quad s^3 = V_{cell}$$



- The equation below relates atomic radius (r) to its volume (V_{atom}).

$$V_{atom} = \frac{4\pi r^3}{3}$$



Q1: Tungsten has a face-centered cubic unit cell. The atomic radius of tungsten is 137 pm. (i) Calculate the volume of the unit cell. (ii) Calculate the total volume of the atoms in the unit cell

A1: (i) $s = [(2c\#)/3]^{1/2} \times r$

$s = [(2)(12)/3]^{1/2} \times 137$ pm

$s = [8]^{1/2} \times 137$ pm

$s = 387$ pm

$V = s^3 = (387 \text{ pm})^3$

$V = \boxed{5.80\times10^7 \text{ pm}^3}$ → ***volume occupied by one unit cell***

(ii) $V_{atom} = 4\pi r^3/3$

$V_{atom} = 4\pi(137 \text{ pm})^3/3$

$V_{atom} = 1.08\times10^7 \text{ pm}^3$

$V_{atom} = 4(1.08\times10^7 \text{ pm}^3)$ → ***there are 4 atoms per unit cell***

$\boxed{V = 4.32\times10^7 \text{ pm}^3}$ → ***volume occupied by the four atoms***

Q2: X-ray diffraction crystallography shows that rubidium has a body-centered cubic unit cell lattice structure that is 564 pm on edge. (i) Calculate the radius of an atom of rubidium in pm. (ii) Calculate the radius of an atom of rubidium in centimeters.

A2: (i) $s = [(2c\#)/3]^{½} \times r$

$564 \text{ pm} = [(2)(8)/3]^{½} \times r$

$r = 244 \text{ pm}$

(ii) $244 \text{ pm} = 244\times10^{-12} \text{ m} \rightarrow 2.44\times10^{-10} \text{ cm}$

Q3: The density of solid copper at STP is 8.960 g/cm^3.

(i) What is the volume of 1 mole of solid copper at STP? ***(This volume includes the total filled and unfilled space)***

(ii) If a copper atom has an atomic radius of 0.128 nm, then calculate the volume of 1 mole copper atoms in cm^3/mol. ***(This volume includes only the filled space)***

(iii) Solid copper forms in cubic unit cells. Determine the type of cell by calculating the packing efficiency of the cell. ***(the percent filled)***

A3: (i) $d = m/V \rightarrow V = m/d$

$V = 63.55\text{g/mol} \div 8.960\text{g/cm}^3$

$V = 7.093 \text{ cm}^3\text{/mol}$

(ii) $V = [4\pi r^3]/3 \times [6.02 \text{ x } 10^{23}]$

$V = [4\pi(0.128 \text{ x } 10^{-7})^3]/3 \times [6.02 \text{ x } 10^{23}]$

$V = 5.29 \text{ cm}^3\text{/mol}$

(iii) $\%\text{Filled} = [5.29 \div 7.093] \times 100$

$\%\text{Filled} = 74.58\% \rightarrow$ face-centered cubic

- The equation below relates the density of a metal (d) to its molar mass (MM), its unit cell volume (V_{cell}), the number of atoms per unit cell, and Avogadro's number (atoms/mol).

$$d = \frac{[\text{molar mass (g/mol)}] \times [\text{\# of atoms per unit cell}]}{[\text{volume of unit cell (cm}^3)] \times [\text{Avogadro's \# (atoms/mol)}]}$$

- The density of metals is usually in units of **g/cm^3**, so pay close attention to the units in the equation.

Q4: Solid iron forms body-centered cubic cells. If the density of iron at STP is 7.874 g/cm^3, then predict the radius (**nm**) of a single atom.

A4: $$d = \frac{[\text{molar mass (g/mol)}] \times [\text{\# of atoms per unit cell}]}{[\text{volume of unit cell (cm}^3)] \times [\text{Avogadro's \# (atoms/mol)}]}$$

$$7.874 \text{ g/cm}^3 = \frac{[55.845 \text{ g/mol}][2 \text{ atoms}]}{[V][6.02\times10^{23}\text{atoms/mol}]}$$

$V = 2.36\times10^{-23} \text{ cm}^3$

****

$V = s^3$

$2.36\times10^{-23} \text{ cm}^3 = s^3$

$s = 2.87\times10^{-8} \text{ cm}$

****

$s = [(2c\#)/3]^{½} \times r$

$2.87\times10^{-8} \text{ cm} = [(2)(8)/3]^{½} \times r$

$r = 1.24\times10^{-8} \text{ cm}$

$$r = 1.24\times10^{-8} \text{ cm} \times \frac{1 \text{ m}}{100 \text{ cm}} \times \frac{1\times10^{9} \text{ nm}}{1 \text{ m}}$$

$r = 0.124 \text{ nm}$

Q5: The alkali metals pack their atoms in body-centered cubic unit cells. Determine (i) the volume of a lithium unit cell in **cm^3** and (ii) lithium's ionic radius in **pm** [d = is 0.534 g/cm^3].

A5: (i) $0.534\ g/cm^3 = \dfrac{[6.941\ g/mol.][\ 2\ atom\ ]}{[\ V\ ][6.02\times10^{23} atoms/mol]}$

$V = 4.32\times10^{-23}\ cm^3$

(ii) $V = s^3$

$4.32\times10^{-23}\ cm^3 = s^3$

$s = 3.51\times10^{-8}\ cm = 351\ pm$ ***(edge length)***

$s = [(2c\#)/3]^{1/2} \times r$

$351\ pm = [(2)(8)/3]^{1/2} \times r$

$r = 152\ pm$

Q6: A pure metallic solid with atoms in a face-centered cubic unit cell whose edge length is 392 pm has a density of 21.45 g/cm^3. Calculate (i) the atomic radius and (ii) the atomic mass of the metal. (iii) What element might this metal be?

A6: (i) $s = [(2c\#)/3]^{1/2} \times r$

$392\ pm = [(3)(12)/3]^{1/2} \times r$

$r = 139\ pm$

(ii) $V = (392\times10^{-10}\ cm)^3 \rightarrow 6.02\times10^{-23}\ cm^3$

$21.45\ g/cm^3 = \dfrac{[X\ g/mol.][\ 4\ atom\ ]}{[6.02\times10^{-23}\ cm^3][6.02\times10^{23} atoms/mol]}$

$X = 194\ g/mol$

(ii) It's most likely platinum

Q7: In a x-ray diffraction crystallography experiment, molybdenum metal was bombarded by x-rays with wavelengths of 71 pm. It was concluded that the radii of molybdenum atoms was 140 pm. If molybdenum's density is 10.2 g/cm^3, then determine the type of unit cells present in molybdenum. ***This requires a "hunt and peck" solution.***

A7: (i) ***Assume it's a simple cubic unit cell.***

$s = [(2)(6)/3]^{1/2} \times 140 \text{ pm} = 280 \text{ pm} \rightarrow \underline{280\times10^{-10} \text{ cm}}$

$V = 2.20\times10^{-23} \text{ cm}^3$

$$d = \frac{[95.94 \text{ g/mol.}][\text{ 1 atom }]}{[2.20\times10^{-23} \text{ cm}^3][6.02\times10^{23} \text{atoms/mol}]}$$

$d = 7.24 \text{ g/cm}^3$ ← ***this isn't right!***

(ii) ***Assume it's a body-centered cubic unit cell.***

$s = [(2)(8)/3]^{1/2} \times 140 \text{ pm} = 323 \text{ pm} \rightarrow \underline{323\times10^{-10} \text{ cm}}$

$V = 3.37\times10^{-23} \text{ cm}^3$

$$d = \frac{[95.94 \text{ g/mol.}][\text{ 2 atom }]}{[3.37\times10^{-23} \text{ cm}^3][6.02\times10^{23} \text{atoms/mol}]}$$

$d = 9.46 \text{ g/cm}^3$ ← ***this isn't right!***

(ii) ***Assume it's a face-centered cubic unit cell.***

$s = [(2)(12)/3]^{1/2} \times 140 \text{ pm} = 396 \text{ pm} \rightarrow \underline{396\times10^{-10} \text{ cm}}$

$V = 6.21\times10^{-23} \text{ cm}^3$

$$d = \frac{[95.94 \text{ g/mol.}][\text{ 4 atom }]}{[6.21\times10^{-23} \text{ cm}^3][6.02\times10^{23} \text{atoms/mol}]}$$

$d = 10.3 \text{ g/cm}^3$ ← ***this is in the ball park!***

Molybdenum atoms pack in face-centered unit cells!

Post AP Exam Topics

Lesson-2

II- Concentrations of Solutions

A) Mass Percent (Percent by Mass):

$$\textbf{\% Mass Solute} = \frac{\textbf{mass solute}}{\textbf{total mass solution}} \times 100$$

Q1: What is the mass percent of glucose if 50.0 g of glucose is dissolved in 100.0 g of water?

A1: $\% \text{ Mass } C_6H_{12}O_6 = \frac{50.0}{150.0} \times 100$

$\% \text{ Mass } C_6H_{12}O_6 =$ 33.3 %

B) Parts per Million (ppm) and Parts per Billion (ppb):

$$\textbf{ppm} = \frac{\textbf{mass solute}}{\textbf{total mass solution}} \times 1\times10^{6}$$

$$\textbf{ppb} = \frac{\textbf{mass solute}}{\textbf{total mass solution}} \times 1\times10^{9}$$

Q2: What is the ppm of 0.90 mg of arsenic in a liter of water?

A2: $\text{ppm} = \frac{0.00090}{1000.0} \times 1\times10^{6}$

ppm = 0.90 ppm

this 90 times the allowable limit for arsenic in US drinking water.

C) Mole Fraction (X):

$$\mathbf{X_{solute} = \frac{moles\ solute}{moles\ solute\ \&\ solvent}}$$

Q3: What is the mole fraction of glucose if 50.0 g of glucose is dissolved in 100.0 g of water?

A3: $X_{glucose} = \frac{0.278}{5.388}$

$X_{glucose} = \boxed{0.0516}$

D) Molality (m):

$$\mathbf{m = \frac{moles\ solute}{kg\ solvent}}$$

Q4: What is the molality of glucose if 50.0 g of glucose is dissolved in 100.0 g of water?

A4: $m_{glucose} = \frac{0.278}{0.1000}$

$m_{glucose} = \boxed{2.78\ m}$ or $\boxed{2.78\ \text{molal}}$

E) Density (g/mL or g/cm^3):

$$\mathbf{d = \frac{grams\ solution}{milliliters\ solution}}$$

Q5: What is the density (in g/mL) of a solution of 571.6 g H_2SO_4 and 757.4 g H_2O if the volume is 1.000 L?

A5: $d = \frac{1329.0}{1000.}$

$d = \boxed{1.329\ \text{g/mL}}$

III - Conversion between Concentration Units

A) Temperature Independent Conversions:

Grams and moles are temperature independent units. When converting from and to concentrations that contain these units, complete the following chart and then convert.

	Grams	Moles
Solute		
Solvent		

Q6: Determine the % Mass and mole fraction of NaCl in a 0.500 m [0.500 mol/kg] aqueous solution.

A6:

	Grams	Moles
Solute		0.500
Solvent	1000.0 g	

	Grams	Moles
Solute	***29.3***	0.500
Solvent	1000.0	***55.5***

$$\%Mass = \frac{\text{mass NaCl}}{\text{total mass}} \times 100 = \frac{29.3}{1029.3} \times 100 = \boxed{2.85\%}$$

$$X_{NaCl} = \frac{\text{moles NaCl}}{\text{total moles}} = \frac{0.500}{56.000} = \boxed{0.0093}$$

Q7: Determine the molality and mole fraction of $C_6H_{12}O_6$ in a 25.0% aqueous solution by mass.

A7:

	Grams	Moles
Solute	25.0	***0.139***
Solvent	75.0	***4.17***

$$\text{molality} = \frac{\text{moles solute}}{\text{kg solvent}} = \frac{0.139}{0.0750} = \boxed{1.85\ m}$$

$$X_{NaCl} = \frac{\text{moles NaCl}}{\text{total moles}} = \frac{0.139}{4.309} = \boxed{0.0323}$$

B) Temperature Dependent Conversions:

Volume is temperature dependent. Thus the use of a conversion factor (often density) and factor-label will be needed to convert to or from any concentration containing a volume unit.

When converting from and to concentrations that contain these units, the chart may also be needed.

Q8: An aqueous solution of HCl is 36.0% by mass and has a solution density of 1.18 g/mL. Determine the molarity of the solution.

A8: $\frac{36.0\text{ g HCl}}{100\text{ g sol'n.}} \times \frac{1.00\text{ mol HCl}}{36.5\text{ g HCl}} \times \frac{1.18\text{ g sol'n}}{1\text{ mL sol'n}} \times \frac{1000\text{ mL}}{1\text{ L}} = \boxed{11.6\text{ M}}$

Q9: If the molarity of an aqueous solution of potassium fluoride is 0.748 M and its density is 1.035 g/mL, then determine the molality and mole fraction of potassium fluoride in the solution.

A9: $\frac{0.748\text{ mol KF}}{1\text{ L}} \times 1\text{ L} \times \frac{58.1\text{ g KF}}{1\text{ mol KF}} = \underline{\underline{43.5\text{ g KF}}}$ (in 1 liter sol'n)

	Grams	Moles
Solute	43.5	0.748
Solvent		

$\frac{1.035\text{ g sol'n}}{1\text{ mL sol'n}} \times 1000\text{ mL sol'n} = \underline{\underline{1035\text{ g sol'n}}}$ (in 1 liter sol'n)

1035 g sol'n - 43.5 g KF = $\underline{\underline{991.5\text{ g water}}}$ (in 1 L sol'n)

	Grams	Moles
Solute	43.5	0.748
Solvent	991.5	55.1

Molality = $\frac{0.748\text{ mol}}{0.9915\text{ kg}} = \boxed{0.754\text{ m}}$

Mole Fraction = $\frac{0.748\text{ mol}}{55.848\text{ mol}} = \boxed{0.0134}$

Q10: The density of acetonitrile (CH_3CN) is 0.786 g/mL, and the density of methanol (CH_3OH) is 0.791 g/mL. A solution is made by dissolving 22.5 mL CH_3OH in 98.7 mL CH_3CN. (i) What is the molality of the solution? (ii) What is the mole fraction of CH_3OH in the solution? (iii) What is the molarity of the solution, assuming that the volumes are additive?

A10: $22.5\text{ mL } CH_3OH \times 0.791\text{ g/mL} = \underline{17.8\text{ g } CH_3OH}$

$$17.8\text{ g } CH_3OH \times \frac{1\text{ mole}}{32.05\text{ g}} = \underline{0.555\text{ mol}}$$

$98.7\text{ mL } CH_3CN \times 0.786\text{ g/mL} = \underline{77.6\text{ g } CH_3CN}$

$$77.6\text{ g } CH_3CN \times \frac{1\text{ mole}}{41.06\text{ g}} = \underline{0.529\text{ mol}}$$

	Grams	Moles
Solute	17.8	0.555
Solvent	77.6	1.89

(i) $m = \frac{\text{mol solute}}{\text{kg solvent}}$

$m = \frac{0.555\text{ mol}}{0.0776\text{ kg}} \rightarrow$ **m = 7.15 molal**

(ii) $X_{CH_3OH} = \frac{\text{mol } CH_3OH}{\text{total moles}}$

$X_{CH_3OH} = \frac{0.555\text{ mol}}{2.45\text{ mol}} \rightarrow$ **$X_{CH_3OH} = 0.227$**

(iii) $M = \frac{\text{mol solute}}{\text{L solution}}$

$M = \frac{0.555\text{ mol}}{0.1212\text{ L}} \rightarrow$ **M = 4.58 molar**

Q11: A sulfuric acid solution that contains 571.6 g H_2SO_4 per liter of solution has a solution density of 1.329 g/mL. Determine (i) the mass percent, (ii) the mole fraction, (iii) the molality, and (iv) the molarity of the H_2SO_4 in this solution.

A11: 1.329 g sol'n/mL sol'n × 1000 mL sol'n = 1329 g sol'n

1329 g sol'n − 571.6 g H_2SO_4 = 757.4 g H_2O

571.6 g H_2SO_4 × 1 mol/98.08 g = 5.828 mol H_2SO_4

757.4 g H_2O × 1 mol/18.02 g = 42.03 mol H_2O

	Grams	Moles
Solute	571.6 g	5.828
Solvent	757.4 g	42.03

(ii) $\%_{H_2SO_4} = \frac{\text{mass solute}}{\text{total mass}} \times 100$

$\%_{H_2SO_4} = \frac{571.6\text{ g}}{1329\text{ g}} \times 100 \rightarrow \%_{H_2SO_4} = \boxed{43.01\ \%}$

(i) $X_{H_2SO_4} = \frac{\text{mol solute}}{\text{total moles}}$

$X_{H_2SO_4} = \frac{5.828\text{ mol}}{47.86\text{ mol}} \rightarrow X_{H_2SO_4} = \boxed{0.1218}$

(iii) $m = \frac{\text{mol solute}}{\text{kg solvent}}$

$m = \frac{5.828\text{ mol}}{0.7574\text{ kg}} \rightarrow m = \boxed{7.694\text{ molal}}$

(iv) $M = \frac{\text{mol solute}}{\text{L solution}}$

$M = \frac{5.828\text{ mol}}{1.000\text{ L}} \rightarrow M = \boxed{5.827\text{ molar}}$

Post AP Exam Topics

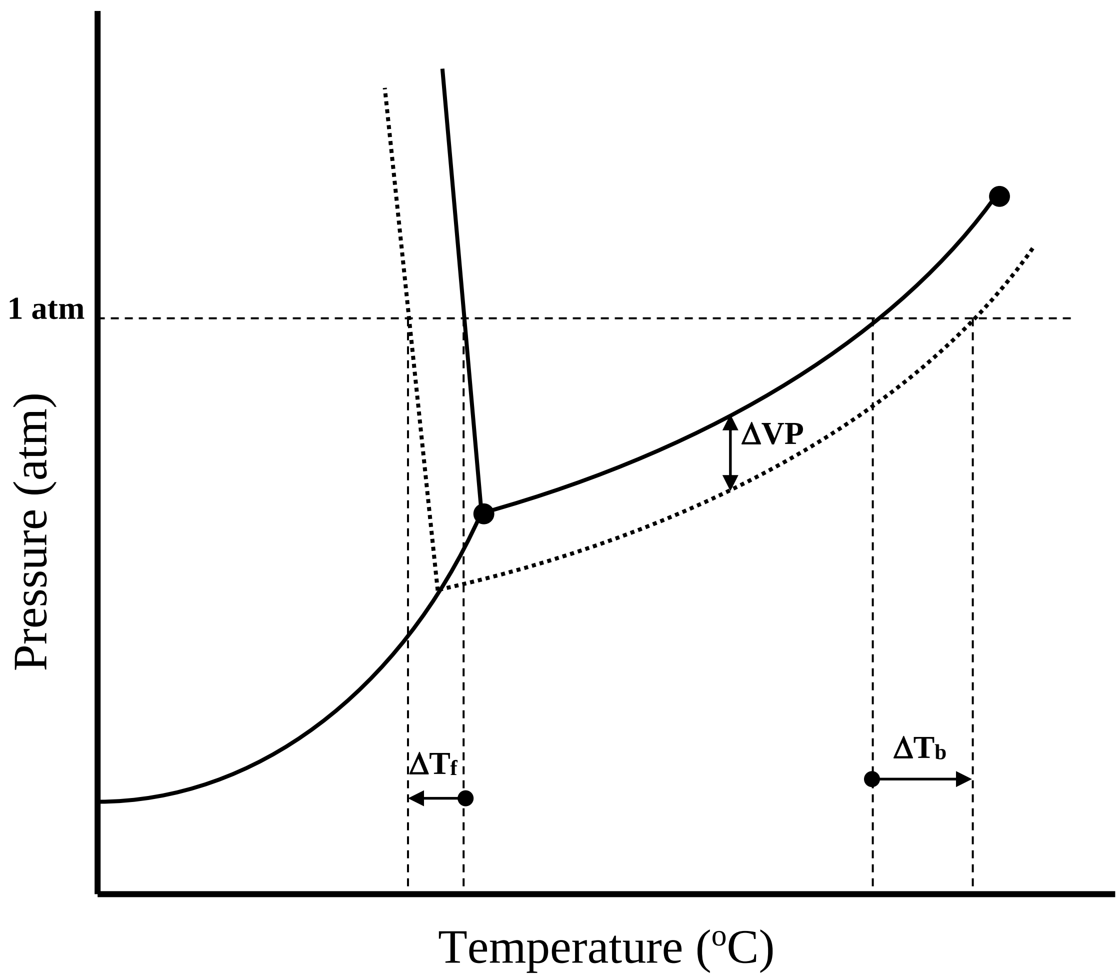
Lesson-3

IV - Colligative Properties

- A Colligative property is one that depends on the total concentration of the dissolved solute particles but not on the nature of the solute itself.
- The relationships among colligative properties and solute concentration are most closely approached in dilute (1M or less) solutions of nonvolatile nonelectrolytes.

A) Vapor Pressure Lowering:

- A solvent with impurities will always have a lower vapor pressure than the pure solvent.



- The relationship between the vapor pressure of a solvent above a solution ($P_{solvent}$) and the mole fraction of the solvent in the solution ($X_{solvent}$) is known as ***Raoult's law***.

$$\mathbf{P_{solvent} = X_{solvent} \times P^o_{solvent}}$$

where $P^o_{solvent}$ is the vapor pressure of the pure solvent.

- If $X_{solvent} + X_{solute} = 1$, then $X_{solvent} = (1 - X_{solute})$. Substituting into Raoult's law…

$$P_{solvent} = (1 - X_{solute}) \times P^o_{solvent}$$

then…

$$P_{solvent} = P^o_{solvent} - (X_{solute} \times P^o_{solvent})$$

then…

$$P^o_{solvent} - P_{solvent} = (X_{solute} \times P^o_{solvent})$$

and thus…

$$\mathbf{\Delta P_{solvent} = X_{solute} \times P^o_{solvent}}$$

where **ΔP** is the vapor pressure lowering of the solvent.

Q1: Calculate the vapor pressure lowering when 100.0 g of glucose (MM = 180.0 g/mol) is dissolved in 100.0 g of water at 20.0°C. (P^o_{water} = 17.5 torr at 20.0°C)

A1: $\Delta P_{water} = X_{glucose} \times P^o_{water}$

$\Delta P_{water} = (.5556 \text{ mol}/6.111 \text{ mol}) \times 17.5$

$\Delta P_{water} = \boxed{1.59 \text{ torr}}$

Q2: Determine the vapor pressure of water if 50.0 g of glycerol (MM = 92.0 g/mol) is dissolved in 100.0 g of water at 0.0°C. (P^o_{water} = 4.6 torr at 0.0°C)

A2: $P_{water} = X_{water} \times P^o_{water}$

$P_{water} = (5.556 \text{ mol}/6.099 \text{ mol}) \times 4.6$

$P_{water} = \boxed{4.2 \text{ torr}}$

B) Boiling Point Elevation and Freezing Point Depression:

- The boiling point of a solution is always greater than that of the pure solvent and its freezing point is always less than that of the pure solvent. This is caused by the vapor pressure lowering of the solvent by the solute.

$$\mathbf{\Delta T_b = k_b m i} \qquad \mathbf{\Delta T_f = k_f m i}$$

where $\mathbf{\Delta T_b}$ is the boiling point elevation, $\mathbf{k_b}$ is the boiling point elevation constant (**H_2O is 0.52**), **m** is the molality of the solution, $\mathbf{\Delta T_f}$ is the freezing point depression, $\mathbf{k_f}$ is the freezing point depression constant (**H_2O is 1.86**), and **i** is the van't Hoff factor.

- Ideally, the van't Hoff factor "i" for electrolytes is equal to the number of ions produced when one solute particle dissolves in water. However, most electrolyte solutions are not ideal.
- The greater the molality of the solution, the greater the deviation between the **ideal-"i"** and the **observed-"i"**.
- The greater the charges of the ions in the solute, the greater the deviation between the **ideal-"i"** and the observed or **real-"i"**.

	ideal (i) NaCl	**ideal (i) $MgSO_4$**	**real (i) NaCl**	**real (i) $MgSO_4$**
0.005 m	2	2	1.96	1.72
0.050 m	2	2	1.89	1.30
0.500 m	2	2	1.81	1.07

Q3: The normal freezing point of p-dichlorobenzene is 53.1°C (k_f = 7.10°C/m). If 1.52 g of sulfanilamide (a nonelectrolytic drug) lowers the freezing point of 10.0 g of p-dichlorobenzene to 46.7°C, then what is the molar mass of sulfanilamide?

A3: $\Delta T = kmi$

$6.4 = (7.10)(x)(1)$

$x = 0.90$ mol/kg

$m = \dfrac{\text{mol solute}}{\text{kg solvent}}$

$0.90\ m = \dfrac{x}{0.0100\ \text{kg}}$

$x = 0.0090$ mol

$\mathcal{M} = m/n$

$\mathcal{M} = \dfrac{1.52\ \text{g}}{0.0090\ \text{mol}}$

$\mathcal{M} = 170$ g/mol

Q4: What are the ideal the van't Hoff factors "i" for the following solutes? (i) $Ca(OH)_2$, (ii) $C_2H_4(OH)_2$, (iii) $Al_2(SO_4)_3$

A4: (i) 3 (ii) 1 (iii) 5

Q5: What is the approximate boiling point of 350.0 g of NaCl dissolved in 1.000 L water? ($k_{b\text{ for water}}$ is 0.52°C/m)

A5: $\Delta T = kmi$

$m = \frac{\text{mol solute}}{\text{kg solvent}}$

$350.0\text{g} \times \frac{1\text{ mol}}{58.5\text{ g}} = 5.98$

$m = \frac{(5.98\text{ mol})}{1.000\text{ kg}}$

$m = 5.98\text{ m}$

$x = (0.52)(5.98)(2)$

$x = 6.2^{o}C$

$T_b = 106.2^{o}C$

Q6: What is the approximate freezing point of 2.00 L of water that has 1120 g of $C_2H_4(OH)_2$ dissolved in it? ($k_{f\text{ for water}}$ is 1.86°C/m)

A6: $\Delta T = kmi$

$m = \frac{\text{mol solute}}{\text{kg solvent}}$

$1120\text{g} \times \frac{1\text{ mol}}{62.0\text{ g}} = 18.0$

$m = \frac{(18.0\text{ mol})}{2.00\text{ kg}}$

$m = 9.00\text{ m}$

$x = (1.86)(9.00)(1)$

$x = 16.7^{o}C$

$T_f = -16.7^{o}C$

Post AP Exam Topics

Lesson-4

V – Alcohols

- Organic compounds are compounds that contain carbon. Organic compounds also usually contain hydrogen as well.
- Compounds containing ONLY carbon and hydrogen are called **hydrocarbons**.
- The simplest class of organic compounds is the **alkane** family.
- The first ten members of the alkane family are:

methane – CH_4;	hexane – C_6H_{14};
ethane – C_2H_6;	heptane – C_7H_{16};
propane – C_3H_8;	octane – C_8H_{18};
butane – C_4H_{10};	nonane – C_9H_{20};
pentane – C_5H_{12};	decane – $C_{10}H_{22}$;

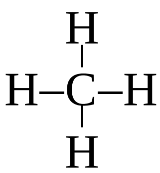
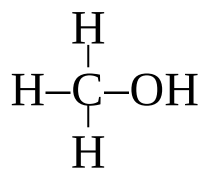
- The carbon-to-hydrogen bonds in hydrocarbons are for all practical purposes nonpolar. THUS hydrocarbons are nonpolar molecules are very insoluble in water.
- Many organic compounds are hydrocarbon derivatives.
- Organic compounds are named by rules set forth by **IUPAC** (the International Union of Pure and Applied Chemistry). The number of carbons in an organic compound is indicated by different root names. The first ten root names and their respective number of carbon atoms are: (**MEMORIZE**!)

1 C – meth, 2 C – eth, 3 C – prop, 4 C – but, 5 C – pent

6 C – hex, 7 C – hept, 8 C – oct, 9 C – non, 10 C – dec

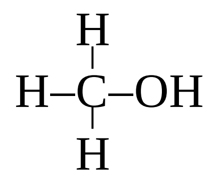
A) Alcohols

- Alcohols are organic compounds that have the **hydroxyl** functional group **(-OH)**.
- Alcohols have the general formula **ROH**.
- Simple alcohols are derivatives of alkanes and are named by dropping the “e” of the corresponding alkane and adding “ol”.


methane →

methanol

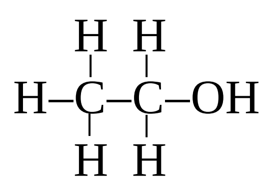
1) **CH_3OH** (methanol or *wood alcohol*)
   - Made from the destructive distillation of wood.
   - Synthesized from carbon monoxide.

$$CO_{(g)} + 2\ H_{2(g)} \longrightarrow CH_3OH_{(\ell)}$$



2) **C_2H_5OH** (ethanol or *grain alcohol*)
   - Made from the fermentation of sugar.

$$C_6H_{12}O_{6(aq)} \longrightarrow 2\ C_2H_5OH_{(aq)} + 2\ CO_{2(g)}$$



   - Synthesized from ethene (*ethylene*).

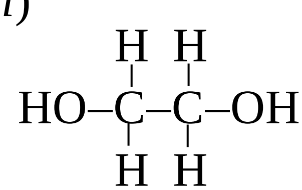
$$C_2H_{4(g)} + H_2O_{(g)} \longrightarrow C_2H_5OH_{(\ell)}$$

   - Both methanol and ethanol can be used as a fuel and both are added to gasoline to produce gasohol.

$$2\ CH_3OH_{(\ell)} + 3\ O_{2(g)} \longrightarrow 2\ CO_{2(g)} + 4\ H_2O_{(g)}$$

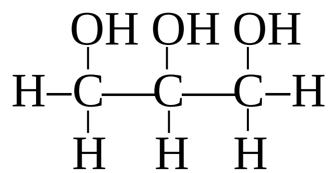
$$C_2H_5OH_{(\ell)} + 3\ O_{2(g)} \longrightarrow 2\ CO_{2(g)} + 3\ H_2O_{(g)}$$

3) **$C_2H_4(OH)_2$** (1,2-ethanediol or *ethylene glycol*)
   - Ingredient in antifreeze.
   - Ingredient in airplane de-icer.



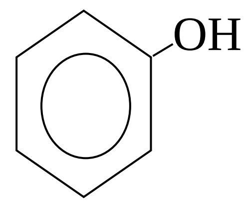
4) **$C_3H_5(OH)_3$** (1,2,3-propanetriol or *glycerol* or *glycerin*)

- Formed as a by-product in the manufacture of soap.
- Ingredient in hand creams, plastics, drugs, & explosives.

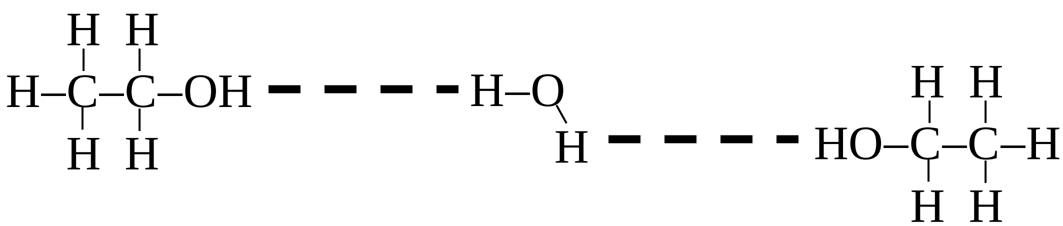


5) **C_6H_5OH** (*phenol*)

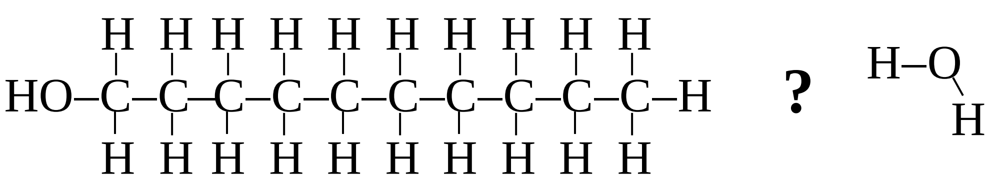
- Used in the manufacture of plastics and dye.
- Used as a topical anesthetic in sore throat sprays.



- Small alcohols are very soluble in water due to the hydroxyl group and its ability to form strong hydrogen bonds with water.



- Large alcohols are very insoluble in water due to the hydrocarbon chain and its inability to form stable attractions with water.

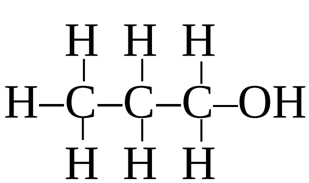


B) Isomers of Alcohols

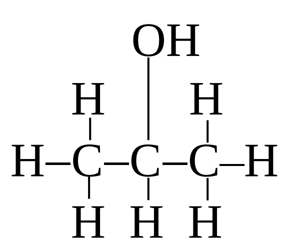
- Monohydroxy alcohols with three or more carbon atoms are able to form isomers.

Q1: There are two isomers of propanol. Draw and then name the complete structural formulas for both isomers of propanol.

A1:



1-propanol



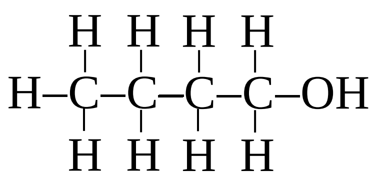
2-propanol (**rubbing alcohol**)

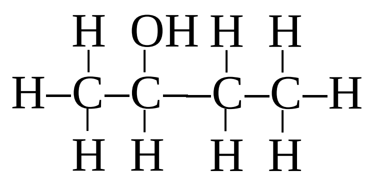
Q2: Which compound, 1-propanol or 2-propanol (**rubbing alcohol**), would you predict to have the lower boiling point and why?

A2: 2-propanol because it is more compact than 1-propanol and thus 2-propanol is less polarizable. This causes the van der Waal's forces holding 2-propanol in the liquid phase to be weaker and thus causing its boiling point to be lower.

Q3: Draw the structural formulas for 1-butanol and 2-butanol.

A3:



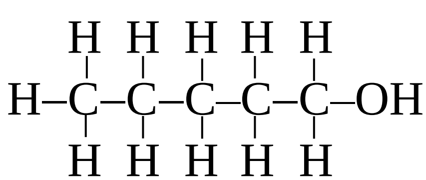


Q4: Why is there no four carbon alcohol named 3-butanol?

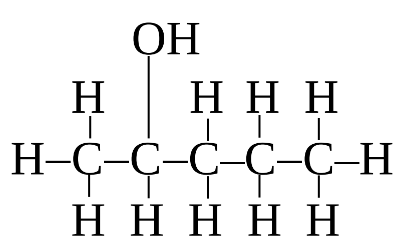
A4: Because when naming organic compounds, the functional group is placed on the lowest numbered carbon possible. Thus, "3-butanol" is really 2-butanol.

Q5: There are several isomers of pentanol. Draw and then name the complete structural formulas for the isomers of pentanol.

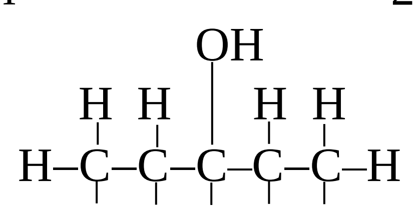
A5:



1-pentanol



2-pentanol



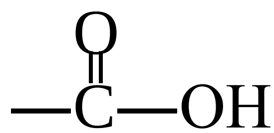
3-pentanol

Post AP Exam Topics

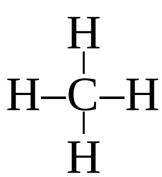
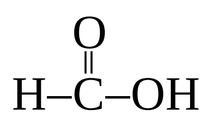
Lesson-5

VI – Carboxylic Acids

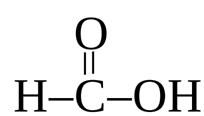
- Carboxylic acids contain a carbonyl group (-CO) coupled with a hydroxyl group (-OH) to form the carboxyl functional group (-COOH).



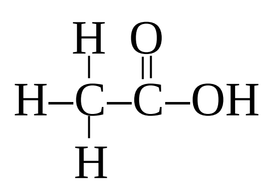
- Carboxylic acids have the general formula **RCOOH**.
- Simple carboxylic acids are derivatives of alkanes and are named by dropping the “e” of the corresponding alkane and adding “oic”.

 methane →  methanoic acid

1) **HCOOH** (methanoic acid or *formic acid*)
    - Found naturally in ants and bees.



2) **CH_3COOH** (ethanoic acid or *acetic acid*)
    - Found naturally in vinegar.
    - Produced from the oxidation of ethanol.

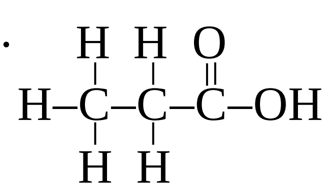


$$C_2H_5OH + O_2 \rightarrow CH_3COOH + H_2O$$

- Synthesized by reacting methanol and carbon monoxide.

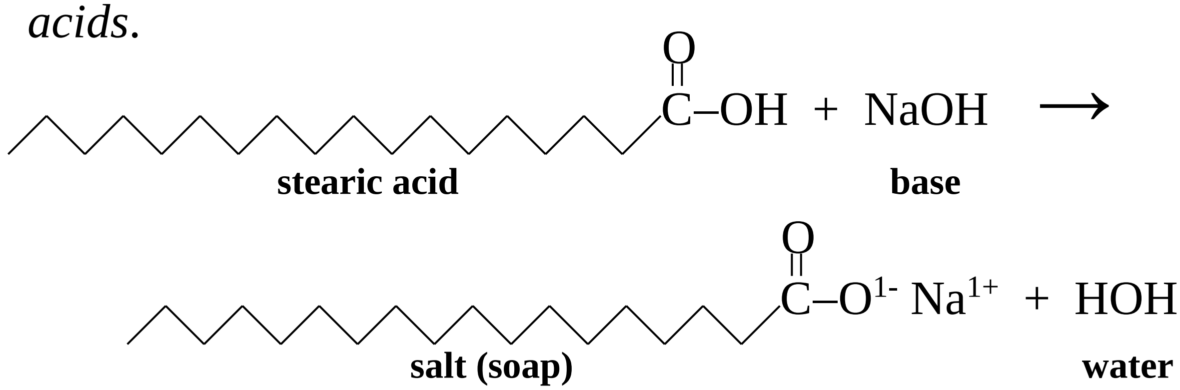
$$CH_3OH + CO \rightarrow CH_3COOH$$

3) **C_2H_5COOH** (propanoic acid or *propionic acid*).
    - Smells like sweat.
    - Produced as an end-product of the anaerobic metabolism of bacteria found in human sweat glands.



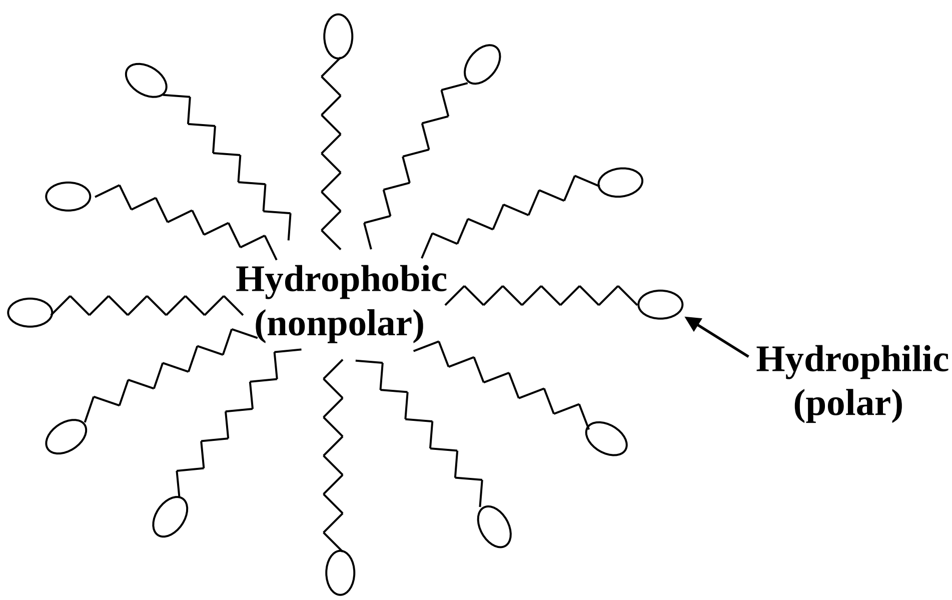
4) **$C_{17}H_{35}COOH$** (*stearic acid*)

- Is an example of a ***fatty acid*** (any carboxylic acid with a long R-group).
- Reacts with NaOH (lye) to make soap. *Soaps are salts of fatty acids*.



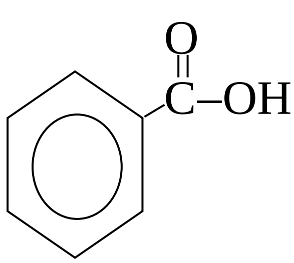
- In water, soap particles arrange themselves in spherical structures called **micelles**.

Micelle:



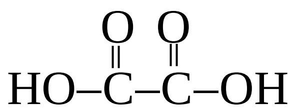
Q1: Benzoic acid is a carboxylic acid in which the R-group is a benzene ring. Draw the structural formula for benzoic acid.

A1:



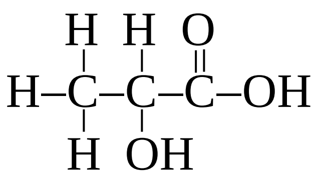
Q2: Oxalic acid is a carboxylic acid that consists of two carboxyl groups bonded to one another. Oxalic acid is naturally found in rhubarb. Draw the structural formula of oxalic acid.

A2:



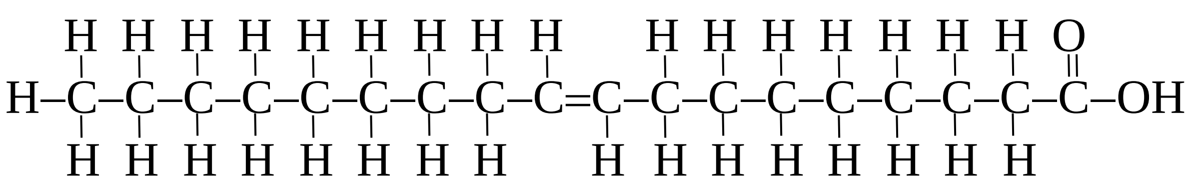
Q3: Lactic acid and propanoic acid have closely related structures. The only difference is that lactic acid also has a hydroxyl group on its second carbon. Draw the structural formula of lactic acid.

A3:

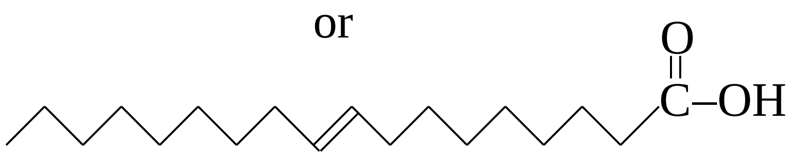


Q4: Oleic acid (found in vegetable oils) and stearic acid (found in animal fats) have closely related structures. The only difference is that oleic acid has a double bond between the ninth and tenth carbon atoms. Draw the structural formula of oleic acid.

A4:



or

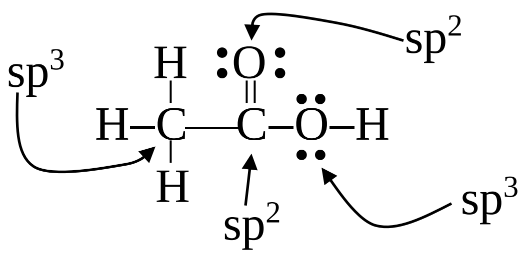


Q5: Name the carboxylic acid C_3H_7COOH which has a very foul odor.

A5: Butanoic acid

Q6: Draw the Lewis structure for ethanoic acid. Identify the hybrid orbitals used by each of the two carbon atoms and each of the two oxygen atoms.

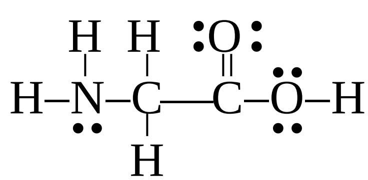
A6:



Q7: Name the carboxylic acid HCOOH which is responsible for the sting in ant bites.

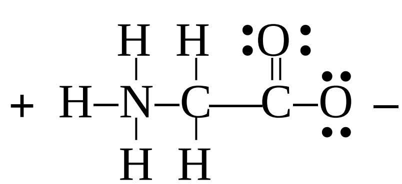
A7: methanoic acid

Q8: Amino acids are organic compounds that contain a carboxylic acid functional group and an amine ($-NH_2$) functional group. Amines are organic bases. The simplest amino acid is glycine (shown below).



In an aqueous solution with a pH near 7, an amino acid exists as a zwitterion (*an ion with both a positive and a negative charge*) in which the ionizable hydrogen from the carboxyl group is transferred to the amine group. Redraw the amino acid above to its zwitterion form.

A8:

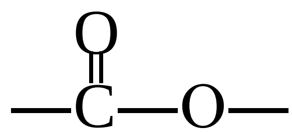


Post AP Exam Topics

Lesson-6

VII – Esters

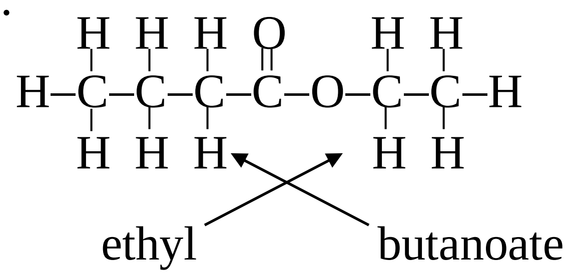
- Esters contain a carbonyl group (-CO) coupled with an oxygen (-O-) to form the ester functional group (-COO-).



- Esters have the general formula **RCOOR**.
- Esters often have pleasant fruity odors.

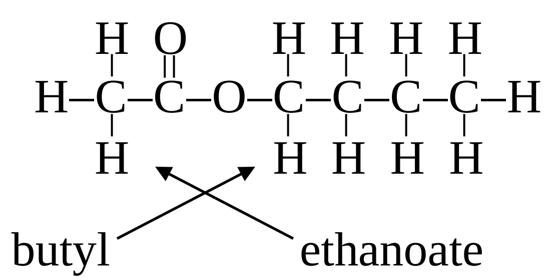
1) **$C_3H_7COOC_2H_5$** (ethyl butanoate)

- Smells like pineapple.



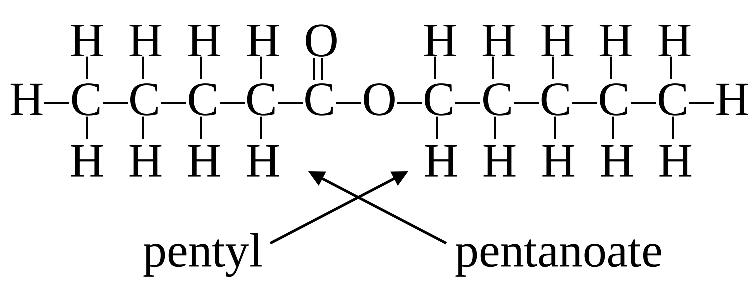
2) **$CH_3COOC_4H_9$** (butyl ethanoate or *butyl acetate*)

- Smells like banana.



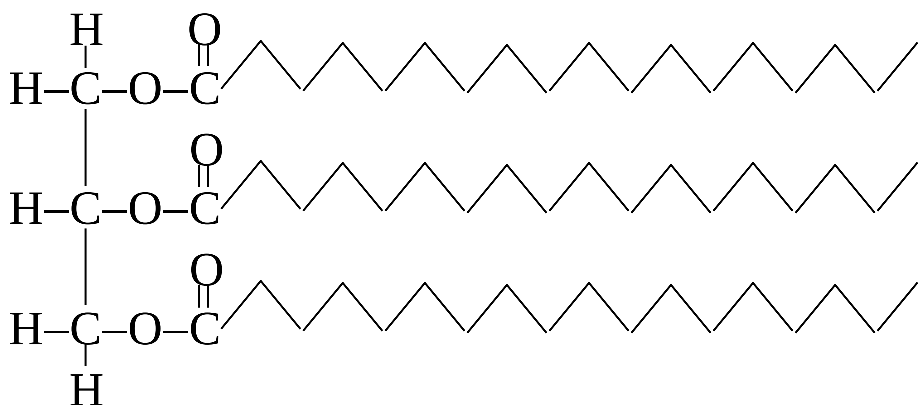
3) **$C_4H_9COOC_5H_{11}$** (pentyl pentanoate)

- Smells like apple.



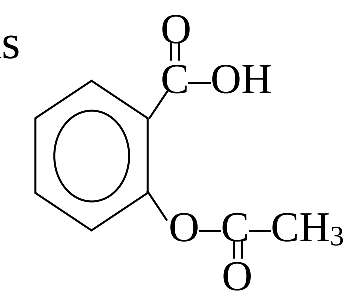
4) **$(C_{17}H_{35}CO)_3O_3C_3H_5$** (*tristearin*)

- A typical <u>saturated</u> (*all carbon-to-carbon bonds are single bonds*) animal fat.



- Tristearin is an example of a triglyceride.

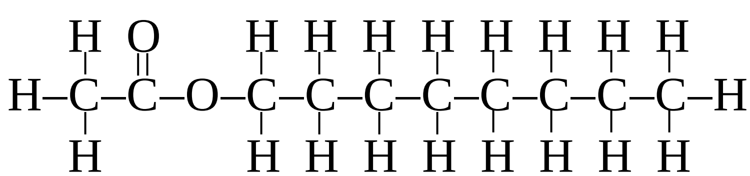
Q1: The aspirin molecule shown to the right has two functional groups. What are they?



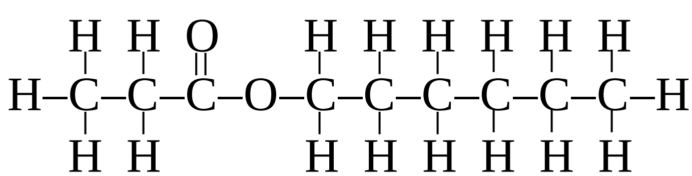
A1: the carboxyl group (–COOH) and the ester group (–COO–)

Q2: The ester octyl ethanoate has the odor of orange. Draw the structural formula for octyl ethanoate.

A2:



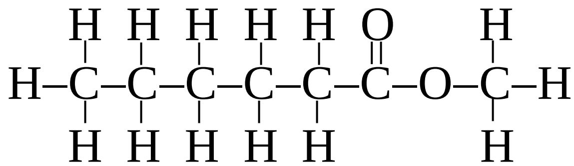
Q3: Name the ester shown below.



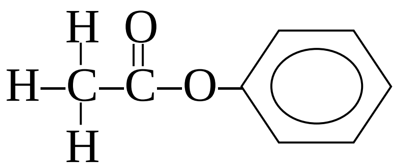
A3: hexyl propanoate

Q4: The ester methyl hexanoate has the odor of strawberries. Draw the structural formula for methyl hexanoate.

A4:



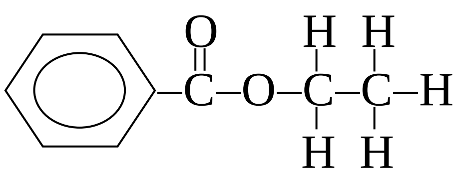
Q5: Name the ester shown below.



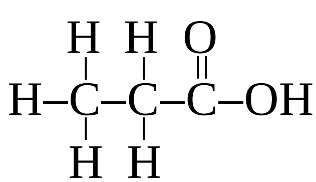
A5: phenyl ethanoate

Q6: The ester ethyl benzoate can be produced from ethanol and benzoic acid. Draw the structural formula for ethyl benzoate.

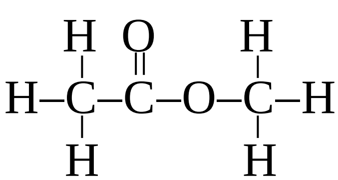
A6:



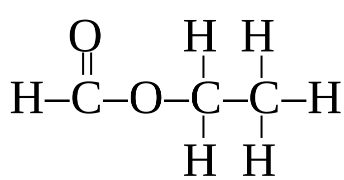
Q7: Most carboxylic acids have at least one ester isomer. Draw and name two different ester isomers of propanoic acid (**shown below**).



A7:



methyl ethanoate



ethyl methanoate

Q8: 1.000 g of an unknown $C_xH_yO_z$ organic compound, whose molar mass is 60.0 g/mol, burns to give 1.466 g of CO_2 and 0.6001 g H_2O. Determine both the empirical and molecular formulas of the unknown organic compound.

A8: $C_xH_yO_z + O_2 \rightarrow CO_2 + H_2O$ ← ***unbalanced skeleton equation***

All the C in the CO_2 & all the H in the H_2O started in the mystery acid!

$$1.466\text{ g }CO_2 \times \frac{1\text{ mol }CO_2}{44.01\text{ g }CO_2} \times \frac{1\text{ mol C}}{1\text{ mol }CO_2} \times \frac{12.01\text{ g C}}{1\text{ mol C}} = \boxed{\mathbf{0.4001\text{ g C}}}$$

$$0.6001\text{g }H_2O \times \frac{1\text{ mol }H_2O}{18.02\text{ g }H_2O} \times \frac{2\text{ mol H}}{1\text{ mol }H_2O} \times \frac{1.01\text{ g H}}{1\text{ mol H}} = \boxed{\mathbf{0.0673\text{ g H}}}$$

The mass of oxygen is found using the Law of Conservation of Mass.

$$\text{mass of oxygen} = 1.000\text{ g} - [0.4001 + 0.0674\text{ g}] = \boxed{\mathbf{0.533\text{ g O}}}$$

The empirical formula can now be determined.

$$0.4001\text{ g C} \times \frac{1\text{ mole}}{12.01\text{ g}} = 0.03331\text{ mol} \div 0.0333\text{ mol} = 1.00$$

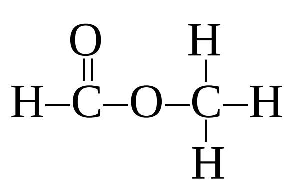
$$0.0673\text{ g H} \times \frac{1\text{ mole}}{1.01\text{ g}} = 0.0666\text{ mol} \div 0.0333\text{ mol} = 2.00 \quad \boxed{\mathbf{CH_2O}}$$

$$0.533\text{ g O} \times \frac{1\text{ mole}}{16.00\text{ g}} = 0.0333\text{ mol} \div 0.0333\text{ mol} = 1.00$$

The empirical formula can now be determined. $\boxed{\mathbf{C_2H_4O_2}}$

Q9: If the unknown organic compound from question-8 were an ester, then draw its structural formula and name the ester.

A9:



methyl methanoate

Post AP Exam Topics

Lesson-7

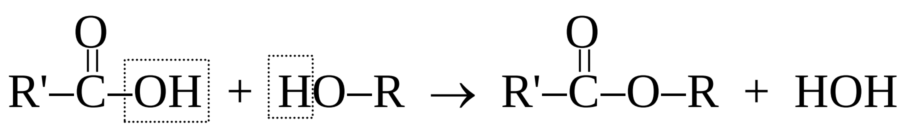
VIII – Esterification

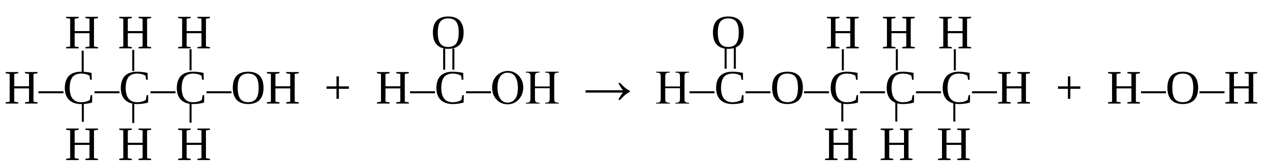
- Esters are formed by reactions between alcohols and carboxylic acids via dehydration synthesis.

$$R'COOH + ROH \rightarrow R'COOR + HOH$$

carboxylic aid **alcohol** **ester** **water**

- Experiment shows that the OH from the acid and the H bonded to the oxygen in the alcohol form the water.

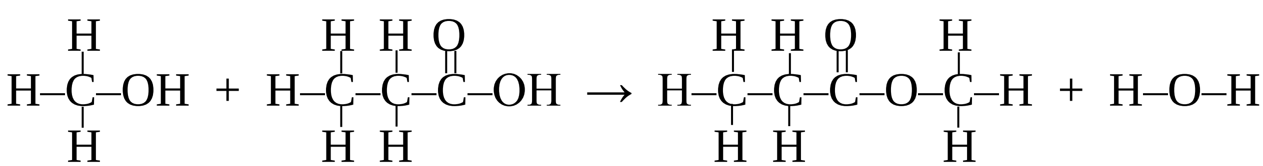




propanol **methanoic acid** **propyl methanoate**

Q1: Write the reaction between methanol and propanoic acid using complete structural formulas and name the organic product.

A1:



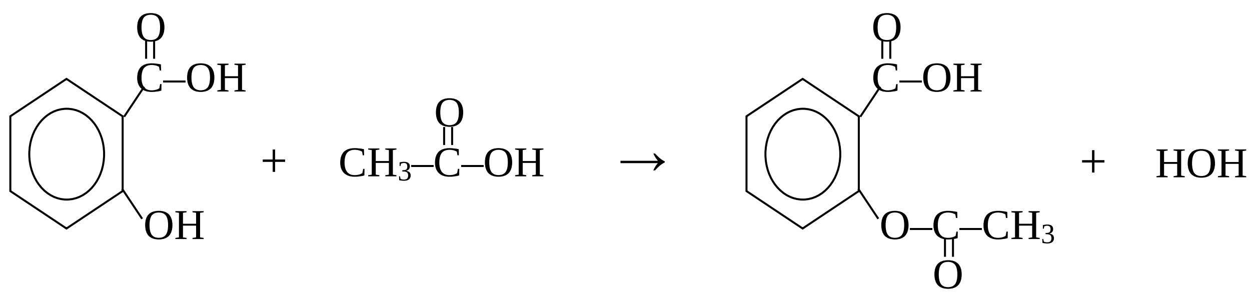
methyl propanoate

Q2: Name the carboxylic acid and alcohol that was used to produce the ester 1-pentyl ethanoate (it smells like apple).

A2: 1-pentanol and ethanoic acid

Q3: Acetylsalicylic acid, known as aspirin, is an ester made from salicylic acid and ethanoic acid (acetic acid). In this reaction, the salicylic acid provides the alcohol group. Complete the reaction below by drawing the structural formula for the Acetylsalicylic acid.

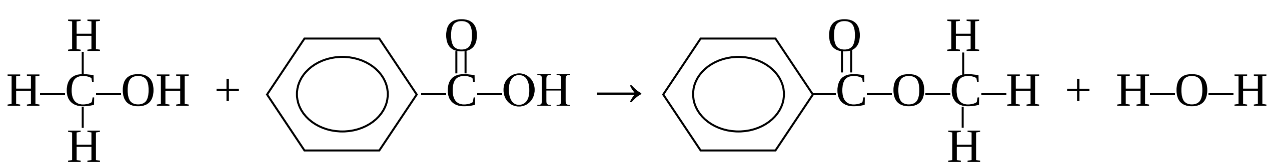
A3:



salicylic acid — acetic acid — acetylsalicylic acid (aspirin)

Q4: Write the reaction between methanol and benzoic acid using complete structural formulas and name the organic product.

A4:



methyl benzoate

Q5: Name the ester that is formed from the dehydration synthesis of ethanol and methanoic acid and which smells like raspberries.

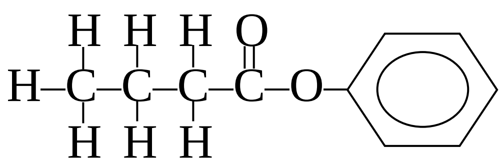
A5: Ethyl methanoate

Q6: Name the carboxylic acid and alcohol that was used to produce the ester phenyl butanoate.

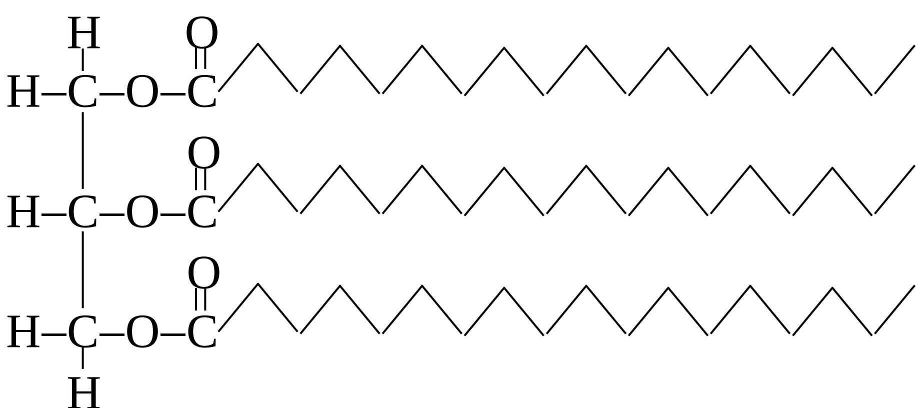
A6: Phenol and butanoic acid

Q7: Draw the structural formulas for the ester phenyl butanoate.

A7:

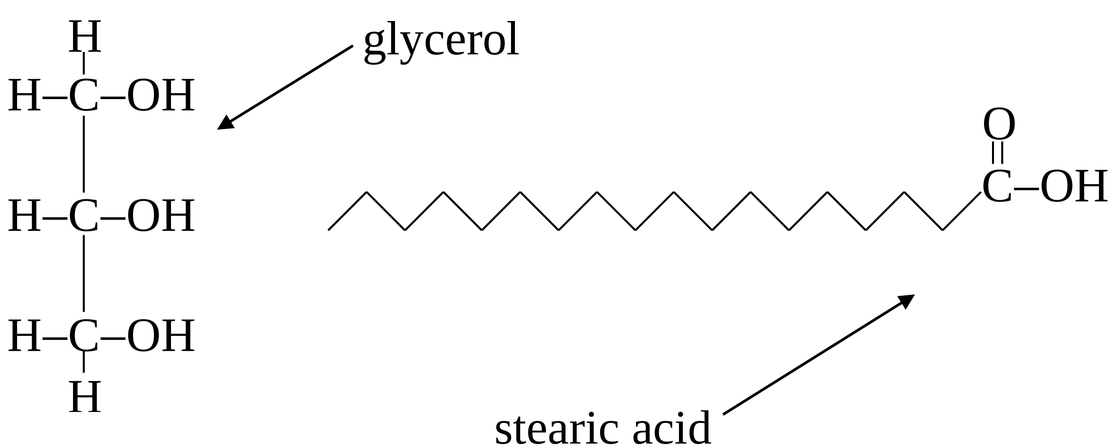


Q8: The animal fat tristearin (shown below) is an ester.



Draw and name the structural formulas for the alcohol and the carboxylic acid that produce the ester tristearin.

A8:

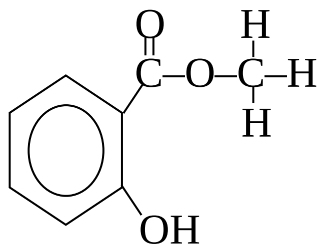


Q9: Name the ester formed by the dehydration synthesis of methanol and salicylic acid.

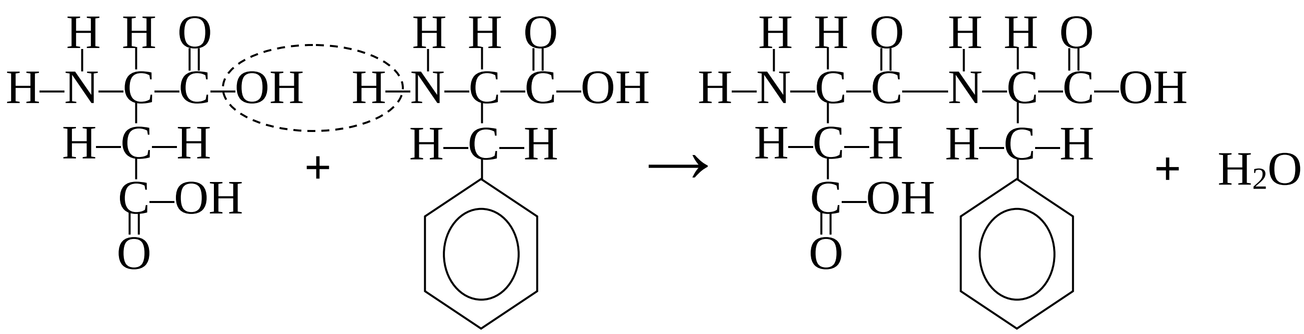
A9: methyl salicylate

Q10: Draw the structural formula for the ester formed by the dehydration synthesis of methanol and salicylic acid.
(See question-3 for the structure of salicylic acid.)

A10:



Q11: Two amino acids can bond through a dehydration synthesis reaction in which the –OH from the carboxylic acid group of one amino acid and an –H from the amine group of the second amino acid is removed to form water. The result is called a dipeptide.



aspartic acid **phenylalanine** **aspartylphenylalanine** **water**

The artificial sweetener, aspartame, is an ester of the dipeptide aspartylphenylalanine and the alcohol methanol. In the esterification, the reacting acid group comes from the phenylalanine portion of the dipeptide. Draw the structural formula for aspartame.

A11: